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Characterization of Exploding Film Plasmas Using Emission Spectroscopy

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***Abstract*-Exploding films have a variety of potential applications including current interrupters, ignition of energetic materials, and sources of intense light. However, characterization of these events remains a challenge as the average duration of an event is only on the order of 100 μs in our studies. An effort to obtain a complete understanding of the exploding film and plasma generation phenomena is underway. This paper investigates the spectral and electrical output of exploding film events on metallized polypropylene film samples. Assuming the plasma generated from the exploding film is a blackbody radiator, peak temperature can be estimated using trends of wavelength versus intensity. This data allows for a more accurate characterization of the plasma that results from the exploding films. A holistic understanding of the deterministic mechanisms of the plasma enables future controllability and tunability in exploding film applications.**

I. Background

Generated plasmas are normally considered harmful elements in power systems as they can result in faults and severe damage to components in the system. However, plasmas can have a variety of useful applications such as pulsed light sources, fuses, and excitation of energetic materials [1].

Research has been performed at the University at Buffalo in an attempt to characterize low energy pulsed plasmas to determine potential applications. Electrical and optical measurements were taken over a large number of experiments to determine the defining characteristics of the plasma created. Polypropylene film samples with an aluminum nano-particle layer on the surface were used as the primary source of plasma generation. When a large amount of energy is released through the film from capacitive discharge over a very short time duration, the aluminum metallization on the polypropylene film vaporizes and enters the surrounding air. The high electric field ionizes the air mixed with the aluminum particles to form a conductive path for current. A short, high-amperage burst of current passes through the ionized air, resulting in a brief high temperature, high optical intensity event. As the aluminum vaporizes from the polypropylene film, the only conductive path for the current (besides the ionized air) essentially disappears. Following the inevitable quenching of the plasma, the energy in the system dissipates and current can no longer flow. The characteristics described in this event lead to its potential applications. Its high optical intensity leads to potential pulsed light source applications, the vaporization of the conductive path leads to potential fusing applications, and high temperature, high energy output allow excitation of energetic materials.

II. Experimental Setup

A series of experiments was performed to obtain the electrical and optical measurements of the pulsed plasma phenomenon. The experimental setup is shown in Fig. 1. A pulse forming network was utilized to produce a large pulse of energy to vaporize the aluminum layer on the polypropylene film. The pulse forming network contains a 2.6 μF capacitor that was charged up to 2.5 kV. A 4-channel Tektronix oscilloscope was used to take voltage and current waveforms of the event. The dimensions of the film used have an influence on the rise time, fall time, action, and duration of the waveform. If the product of the voltage and current is integrated over the duration of the event, the energy of the reaction can be obtained.

However, in order to fully characterize the event, optical measurements must be taken as well. This was accomplished by using the MS125 1/8m Spectrograph from Spectra-Physics. The spectrograph was used to obtain light intensity measurements in the wavelength domain, with a readable range of 300 nm to 1300 nm.

Initial experiments showed that a reliable technique of capturing the light from the event would have to be developed. The first experiments were performed using an integration time of 200 μs, and with the film sample placed on a table facing upward, and the spectrograph on the same table facing toward the sample.

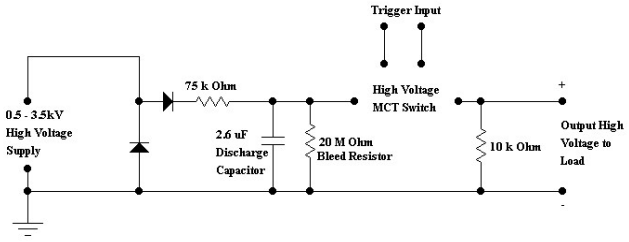

Fig. 1. Experimental Setup.

The spectrograph was set to trigger externally at the same time that the pulse from the pulse forming network was initiated and accumulate all the photons from the event over the duration of the integration time. This yielded no spectrographic results above the noise floor. It was then

hypothesized that a focusing lens system would be necessary to ensure that enough of the light from the event was passed through the slit of the spectrograph to provide data above the noise floor. First, a collimating lens was used to gather a large area of light and direct it toward a focusing lens. The focusing lens focused the light into the slit on the spectrograph. A diagram of the setup is shown in Fig. 2. The test samples were placed at the focal length of the collimating lens, and the lenses were placed in a manner to match the f/# of the spectrograph. A number of tests were performed with the film samples in different configurations in an attempt to optimize the amount of light passing through the slit on the spectrograph. Fig. 3 shows the various configurations that were used in the experimental setup. Yet again, no results above the noise floor were obtained from the spectrograph. The integration time of the spectrograph was changed to 30 ms (the highest internal integration time) to ensure that all of the light emitting from the event was being measured. All of the previous experiments were repeated at this new integration time. Again, no results above the noise floor were obtained.

The next hypothesis for the lack of results was that the duration and/or synchronization of the event were not adequate to provide any spectrographic measurements. To test this hypothesis, a 555 timer circuit with a red LED light source was used in place of the film sample.

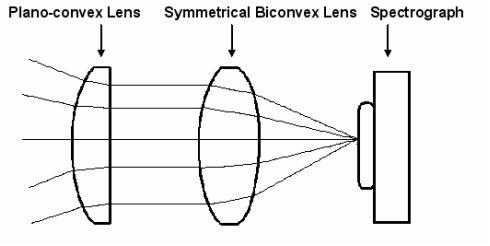

Fig. 2. Lens configuration for experimental setup.

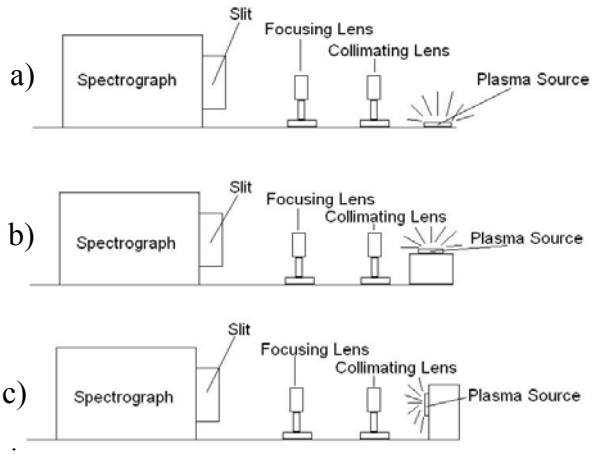

Fig. 3. Physical configurations for experiments.

The duration of the LED pulse was set to the average duration of the film sample tests and was triggered in the same manner as the samples were. Due to the LEDs low optical intensity, the lens system was removed and the LED was placed facing the slit on the spectrograph and a few centimeters away from it. Spectrographic data was obtained from these tests. High intensities were seen around 600 nm. These tests confirmed that the duration and synchronization were not the causes of the lack of results with previous tests.

With the success of the LED experiments, the same setup was used except that the LED was replaced by the film samples. The film samples were placed at the same height as the slit, facing the slit, and a few centimeters away from it. Experiments were performed and again, no spectrographic data above the noise floor was obtained.

III. Analysis And Results

Electrical and optical measurements were taken during the experiments. The waveforms from the digital oscilloscope were analyzed to determine power and energy consumption. Several thousand samples were taken over the duration of the event, which averages around 100 µs. The Reimann sum method was used to determine the energy over the duration of the event. An example of the voltage and current waveforms is shown in Fig. 4. Typical peak values of voltage and current are 2.5 kV and 1.2 kA, respectively. The waveform in Fig. 4 represents a film with a thickness of 7 µm, a sheet resistance of 1 Ω /square, and dimensions of 12.7 cm by 0.318 cm. Fig. 5 shows the product of the current and voltage waveforms. By integrating this waveform over time, the resultant energy is found to be 5.65 J.

Assuming that the plasma is a blackbody radiator, the temperature of the plasma can be determined based on the wavelengths of light seen by the spectrograph.

$$\lambda T = b \tag{1}$$

Equation (1) is used to calculate temperature where b is Boltzmann's constant (2.898 x 10^{-3} m*K), λ is wavelength, and T is temperature [2].

$$U(T) = \sigma T^4 \tag{2}$$

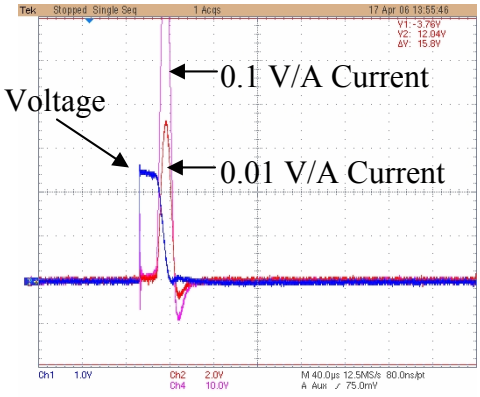

Fig. 4. Voltage and current waveforms.

The emissive power as a function of temperature is described by the equation where U(T) is the emissive power, σ is a constant (5.67 x 10^{-8} W m^{-2} K^{-4}), and T is temperature [2]. Thus, by measuring the wavelength where a peak optical intensity occurs, the temperature and emissive power of the plasma can be estimated.

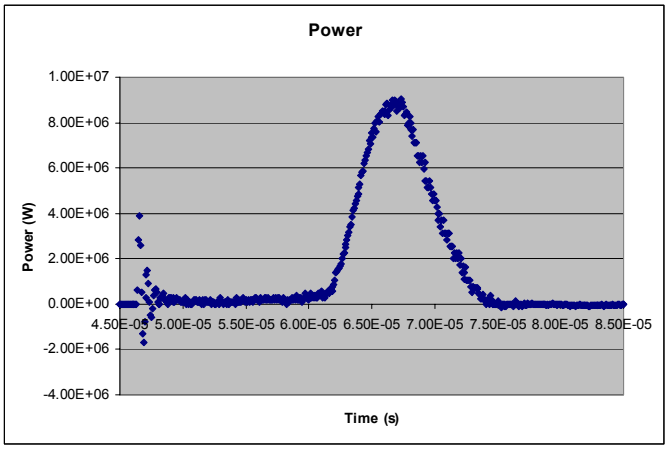

Fig. 5. Power over time of exploding film.

The spectrograph data was recorded digitally in the wavelength domain. The obtained data shows relative intensity with respect to wavelength over the range of 300 nm to 1300 nm. However, despite the fact that a large number of different experiments were performed to obtain the spectrographic data, the desired results were not achieved. It is possible that these results, in fact, mean that the temperature is not within the readable range of the spectrograph. This means that, according to (1), T < 2230 K or T > 9660 K. With these bounds of temperature, U(T) < 1.40 x 10^{6} W/m^{2} or U(T) > 4.937 x 10^{8} W/m^{2}. Future work will continue to try to obtain the spectrographic data of the transient plasma

IV. Conclusion

Measurement and analysis of short time duration transient events is a challenge, especially with regards to a dynamic plasma. By combining electrical and optical measurements, a greater understanding of a transient plasma can be achieved. Successful electrical characterization of the event has been performed, but optical characterization remains elusive. Perhaps the lack of spectrographic results is because any high intensity peaks that may occur are outside the readable range of the spectrograph. This was not expected as the experiments produce a very bright white-blue light. It is also conceivable that although the flash appears bright to the human eye, it may not be passing enough photons into the spectrograph to obtain data above the noise floor. Future experiments will be performed to verify the validity of these possibilities.

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